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DETERMINING THE LOCATION AND SHAPE OF A TOWED ARRAY USING LOW-F--ETC(U)

MAY 79 P W JAMESON N00014-76-C-1151

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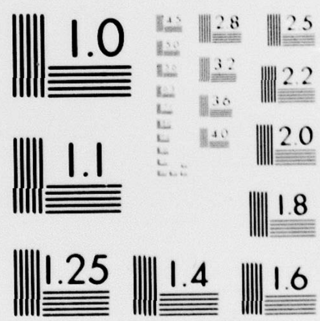

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Report No. 4117

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P.W. Jameson

May 1979

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DETERMINING THE LOCATION AND SHAPE OF A TOWED ARRAY USING LOW-FREQUENCY ELECTROMAGNETIC FIELDS

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Introduction

At the present time, there is only one demonstrated practical method of measuring the position of the hydrophone elements of a long submerged hydrophone array towed by a surface ship. This method is to measure the distance of the hydrophones from an acoustic source remote from both the towed array and the towing ship. The process of deploying a remote acoustic source presents practical difficulties that make this measurement technique difficult and inconvenient for continuous use.

In this paper we describe an untried but apparently feasible method that uses electromagnetic fields generated at the towing ship. These electromagnetic fields would be generated by sending a large pulsed current through electrodes suspended in the ocean at equal depth behind the towing ship. The electrodes would be connected by a long straight horizontal insulated conductor broken at its center and antisymetrically fed from a high-current source.

Description of the Electromagnetic Fields

The center-fed insulated conductor can be treated as a line having constant current I and length ℓ where ℓ is the distance between the electrodes (see Fig. 1). This line of constant current can be considered as a current dipole of strength p, equal to $I\ell$. We will assume that the dipole is fed from a shielded cable that does not radiate. The electromagnetic fields of a submerged dipole have been computed by a number of authors, perhaps most notably by A. Sommerfeld [1], J.R. Wait

[2], R.K. Moore [3], and A. Baños [4]. The methods of calculation all use an image dipole above the surface and the matching of boundary conditions at the air-water interface. We will use the results of the calculation as described by Baños in *Dipole Radiation in the Presence of a Conducting Half-Space*.

We employ a cylindrical coordinate system with the z-axis vertical and increasing in the upward direction. The surface of the ocean will be considered to define the plain $z = 0$. The underwater dipole will be perpendicular to, but have its center on, the axis of the system at z equal to $-h$, where h is the magnitude of the depth. The azimuthal angle ϕ will designate angular orientation in the horizontal plane. The angular orientation of the dipole will be considered to define the origin $\phi = 0$. The coordinate system is shown in Fig. 2.

At a relatively great distance from the dipole source, but for depths below the surface that are small compared to this distance, the electric and magnetic fields have a simple form,

$$E_r = \frac{p}{2\pi\sigma r^3} \cos\phi \, e^{ik_1(h-z)-i\omega t}$$

$$E_\phi = \frac{p}{\pi\sigma r^3} \sin\phi \, e^{ik_1(h-z)-i\omega t}$$

$$H_r = \frac{ip}{\pi k_1 r^3} \sin\phi \, e^{ik_1(h-z)-i\omega t}$$

$$H_\phi = \frac{-ip\cos\phi}{2\pi k_1 r^3} e^{ik_1(h-z)-i\omega t}, \text{ for } z < 0,$$

where E_r, E_ϕ and H_r, H_ϕ are radial and azimuthal components of the Fourier components of the electric and magnetic fields respectively. The quantity σ represents the conductivity of the ocean, and k_1 represents the complex propagation constant in the ocean at radian frequency ω ($2\pi f$) equal to $\sqrt{i\omega\sigma\mu_0}$. The quantity μ_0 is the permeability of free space. The physical and mathematical picture corresponding to the fields described by these equations is one of fields that propagate up to the surface from the dipole (e^{ik_1h}), spread over the surface of the ocean virtually instantaneously, but fall off with distance as "near fields" of a dipole ($\cos\phi/2\pi r^3$), and then propagate back into the ocean (e^{-ik_1z}). In all of the previous discussion, the propagation constant k_1 is understood to correspond to "propagation" with high attenuation. We assume that the frequencies of interest are sufficiently low that useable signals remain after the up and down propagation loss.

Measurement of Orientation and Location

The fields produced by such a dipole source as we have described could be measured at a towed array by either electric or magnetic sensors, or by both of these. Electric sensors would consist of metal electrodes in contact with the ocean. Magnetic sensors might consist of a wire helix embedded in the hosewall of a module. We consider the sensors on the towed array to be located as shown in Fig. 3.

The voltage difference between electrodes n and n+1 on the array is given by the line integral of the electric field along the module between the electrodes. Assuming the towed array to be locally straight and far away from the source, we deduce that

$$V_n - V_{n+1} = \ell' \frac{p\, e^{ik_1(h-z_n)-i\omega t}}{\pi\sigma r_n^3} \left(-\sin\phi_n \sin\theta_n + \frac{\cos\phi_n \cos\theta_n}{2}\right) ,$$

where ℓ' is the length of a module. The voltage received by the wire helix will be proportional to the magnetic field on the axis of the helix, which will be given by the expression

$$H_{helix} = \frac{ip}{\pi k_1 r_n^3} e^{ik_1(h-z)-i\omega t}\left(\sin\phi_n \cos\theta_n - \frac{\cos\phi_n}{2} \sin\theta_n\right) .$$

It doesn't look as if knowledge of these two signals alone is sufficient to determine ϕ and θ directly.

However, if a second horizontal dipole perpendicular to the first is employed, it becomes possible to determine ϕ and θ. One way to determine the values of ϕ and θ is to measure the magnetic field on the axis of an array module when the second dipole is excited. In this case, the response of the magnetic field on axis will be given by

$$H_{axis} = \frac{ip_\perp}{\pi k_1 r_n^3} e^{ik_1(h-z)-i\omega t}\left(\cos\phi_n \cos\theta_n + \frac{\sin\phi_n \sin\theta_n}{2}\right) ,$$

where we have designated the strength of the second dipole as $p_\perp$.

If the quantities other than the trigonemetric factors in brackets are known, we can then solve for the value of the quantity in brackets.

For example,

$$\cos\phi_n\cos\theta_n + \frac{\sin\phi_n\sin\theta_n}{2} = \frac{H_{axis}\pi k_1 r_n^3}{ip_\perp} e^{-ik_1(h-z)+i\omega t}$$

$$\equiv h(\phi,\theta) \ .$$

Proceeding similarly with the expression for voltage,

$$-\sin\phi_n\sin\theta_n + \frac{\cos\phi_n\cos\theta_n}{2} = \frac{V_n - V_{n+1}\pi\sigma r_n^3}{\ell' p} e^{-ik_1(h-z)+i\omega t}$$

$$\equiv v(\phi,\theta) \ .$$

By using trigonometric formulas, one can show that

$$\phi_n = \frac{1}{2}[\cos^{-1}(0.4h+1.2v)+\cos^{-1}(1.2h-0.4v)]$$

$$\theta_n = \frac{1}{2}[\cos^{-1}(0.4h+1.2v)-\cos^{-1}(1.2h-0.4v)]$$

Thus the angular position and orientation of the towed array module can be determined.

The sum of the source and sensor depth can be determined from the frequency dispersion of the received signal relative to the transmitted one. The measured voltage response relative to $p_\perp$ is insensitive to the angles ϕ and θ as long as they are small. Therefore,

$$i(h-z) \simeq \frac{d}{dk}\,\ell n\,\frac{V_n(\omega)-V_{n+1}(\omega)}{p_\perp(\omega)}$$

$$= 2\sqrt{\frac{\omega}{i\mu_0\sigma}}\,\frac{d}{d\omega}\,\ell n\,\frac{V_n(\omega)-V_{n+1}(\omega)}{p_\perp(\omega)}$$

Power Requirements

An estimate of the power required to achieve usable signal-to-noise ratios has been performed. There are at least five sources of noise: electronic noise, electric noise caused by distant lightning, local ocean height changes in the form of surface waves, irregularities in the conductivity of the ocean, and mechanical deformation of the electrodes. We have estimated explicitly the effect of the first two noise sources.

If the system were to operate with periodic pulses of very low frequency dipole current, perhaps on the order of 1 to 10 Hz, noise from distant lightning would dominate the receiver electronic noise. Measurements taken over Colorado indicate that the average value of the spectral density of the vertical component of the electric field associated with distant lightning is about

$$10^{-7.5}\ (\text{volts/m})^2 \text{per Hz}.$$

We assume that the length of the dipole L is 8 meters and that the electrodes have a diameter of 30 cm. The electrode diameter leads to a value of $\frac{1}{4}$ ohm for the resistance of the water path of the current.

Our rough estimates of power required to operate the electrodes at a 1% duty cycle indicate that an average power into the ocean, in the form of I^2R losses of 15 kilowatts, would allow one to measure angular deflections of the order of a few degrees at a range of 400 meters. This assumes that the receiver is well shielded from the transmitter. The power requirements for sensing depth would be substantially less than this, since the field used to measure depth is substantially in the direction of the array module.

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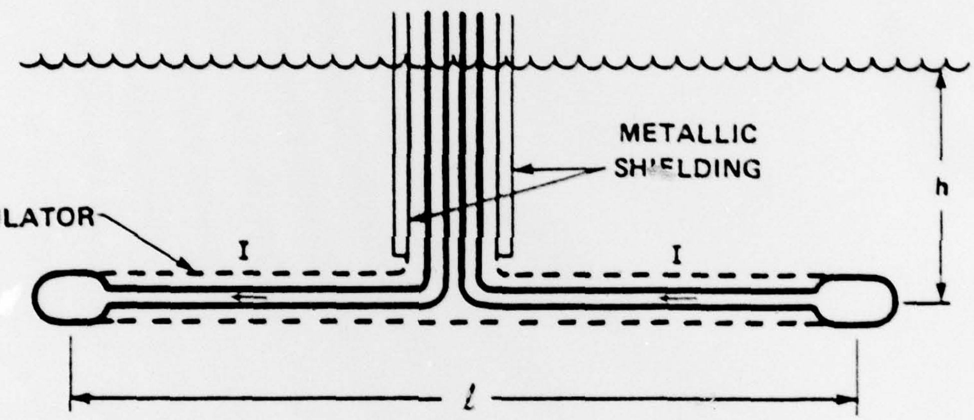

FIGURE 1. UNDERWATER CONDUCTOR AND ELECTRODES.

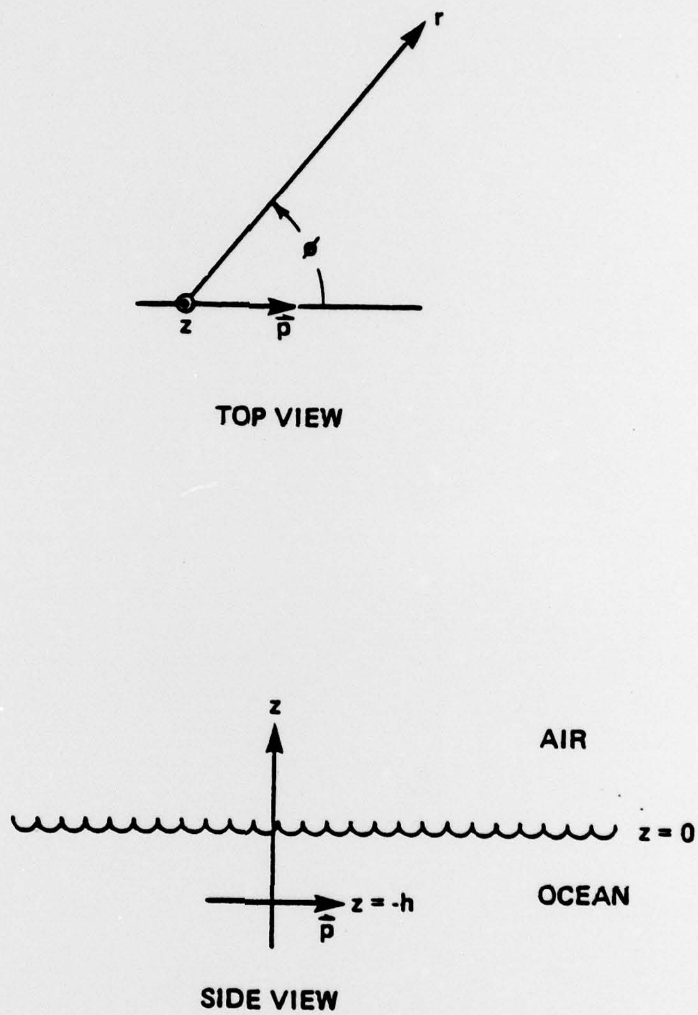

FIG. 2. COORDINATE SYSTEM.

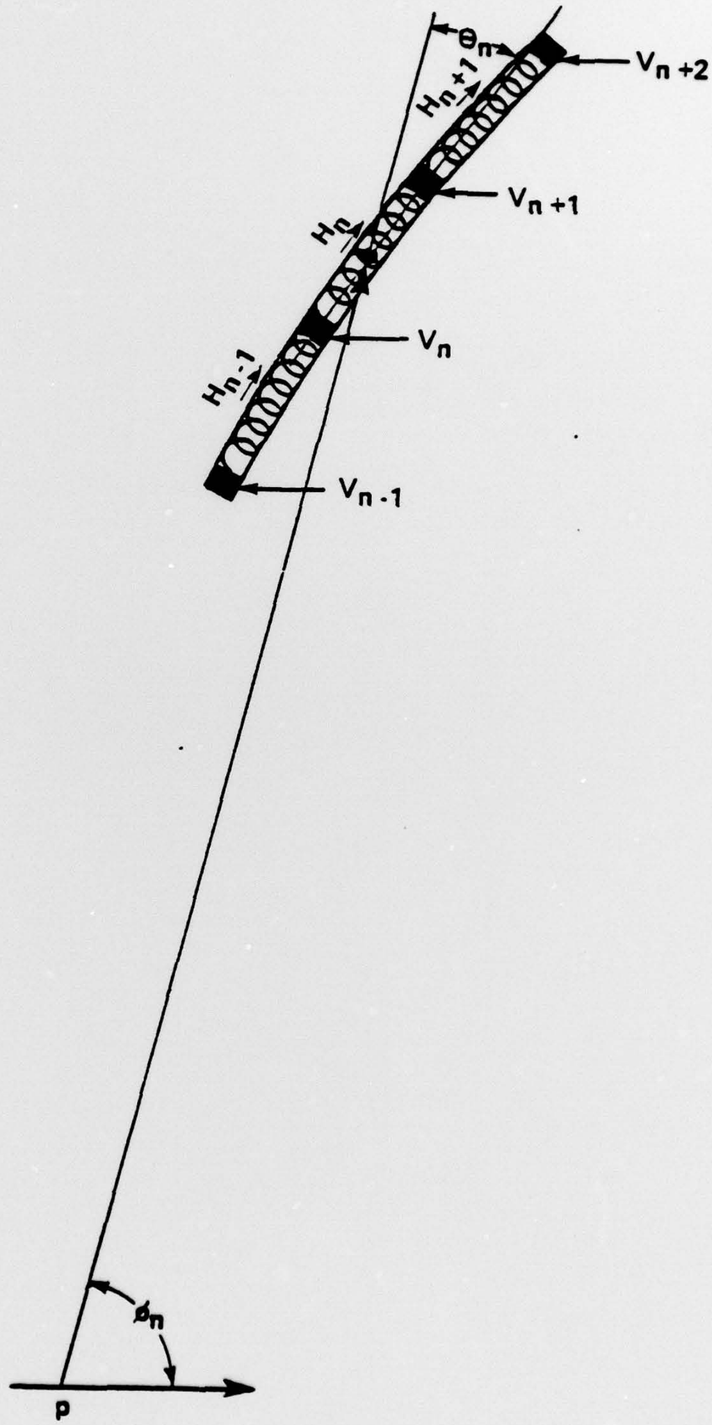

FIG. 3. TYPICAL SECTION OF TOWED ARRAY SHOWING POSITION OF SENSORS.